Medizinische Biophysik

21

Transportprozesse

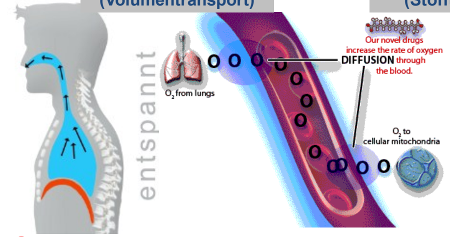
Diffusion

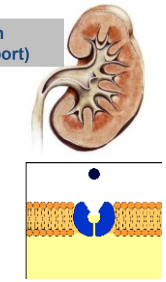
1

Transportprozesse

II. Strömung (Volumentransport)

III. Diffusion (Stofftransport)





I. Elektrischer Strom (el. Ladungstransport)

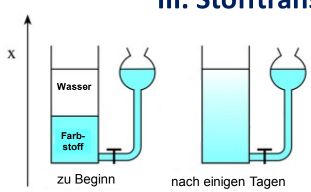
IV. Wärmeleitung (Energietransport)

V. Verallgemeinerung

VI. Energetische Aspekte

2

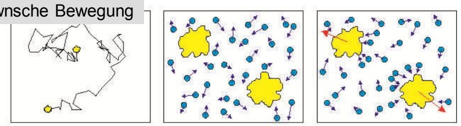
III. Stofftransport (Diffusion)



Adolf Fick
1829-1901
Physiologe

0. Grundvoraussetzung: thermische Molekularbewegung

brownsche Bewegung

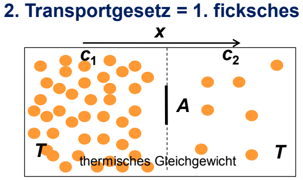


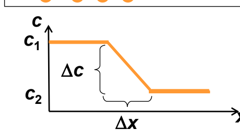
3

1. Grundbegriffe

- Stoffstromstärke (I): (Diffusionsstromstärke) $\quad I = \frac{\Delta \nu}{\Delta t} \quad \left(\frac{\text{mol}}{\text{s}}\right)$
- Stoffstromdichte (J): (Diffusionsstromdichte) $\quad J = \frac{\Delta \nu}{A \cdot \Delta t} \quad \left(\frac{\text{mol}}{\text{m}^2 \cdot \text{s}}\right)$
- stationäre Diffusion: zeitlich konstant

2. Transportgesetz = 1. ficksches Gesetz





$$\frac{\Delta \nu}{\Delta t} = -DA\frac{\Delta c}{\Delta x}$$

$$\boxed{J = -D\frac{\Delta c}{\Delta x}}$$

Stromdichte

Diffusions-koeffizient (m^2/s)

Konzentrations-gradient

4

Analogie

	Was strömt?	Stärke?	Was treibt die Strömung?		Zusammenhang?
Ladungs-transport	q	$J_q = \frac{\Delta q}{A \cdot \Delta t}$	φ	$-\frac{\Delta\varphi}{\Delta l}$	$J_q = -\sigma \frac{\Delta\varphi}{\Delta l}$
Volumen-transport	V	$J_V = \frac{\Delta V}{A \cdot \Delta t}$	p	$-\frac{\Delta p}{\Delta l}$	$J_V = -\frac{R^2}{8\eta}\frac{\Delta p}{\Delta l}$
Stoff-transport	ν	$J_\nu = \frac{\Delta \nu}{A \cdot \Delta t}$	c	$-\frac{\Delta c}{\Delta x}$	$J_\nu = -D\frac{\Delta c}{\Delta x}$

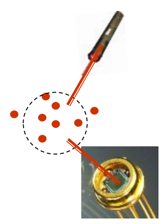
- **Diffusionskoeffizient:**

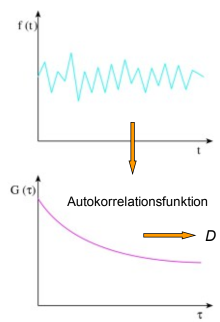
  - stoffspezifisch
    - diffundierende Moleküle – Größe (r) – Form
    - Medium (η)
  - temperaturabhängig $D \sim e^{-\frac{\Delta E}{RT}}$
  - Einstein-Stokes-Gleichung (für kugelförmige Teilchen)

$$\boxed{D = \frac{kT}{6\pi\eta r}}$$

Diffundierendes Teilchen (Molmasse)	**Medium**	***D*** **(m²/s)**
H_2 (2)	Luft	$6{,}4 \cdot 10^{-5}$
O_2 (32)	Luft	$2 \cdot 10^{-5}$
CO_2 (44)	Luft	$1{,}8 \cdot 10^{-5}$
H_2O (18)	Wasser	$2{,}2 \cdot 10^{-9}$
O_2 (32)	Wasser	$1{,}9 \cdot 10^{-9}$
Glyzin (75)	Wasser	$0{,}9 \cdot 10^{-9}$
Serum Albumin (69 000)	Wasser	$6 \cdot 10^{-11}$
Tropomiozin (93 000)	Wasser	$2{,}2 \cdot 10^{-11}$
Tabakmosaik-virus (40 000 000)	Wasser	$4{,}6 \cdot 10^{-12}$

- Messung:
  eine Möglichkeit – dynamische Lichtstreuungsmessung





- **Im thermischen Nichtgleichgewicht:**

  Konzentration (c) ⇒ chemisches Potenzial (μ)

$$\mu = \mu_0 + RT \ln \frac{c}{c_0} \qquad [\mu] = \frac{\mathrm{J}}{\mathrm{mol}} \qquad \left(\text{Falls } c_0 = 1 \text{ mol/l, dann } \mu = \mu_0 + RT \ln c\right)$$

Normalpotenzial

Die Treibkraft der Diffusion im Allgemeinen: $-\frac{\Delta\mu}{\Delta x}$

3. Das 2. ficksche Gesetz:

$$D\frac{\Delta\left(\frac{\Delta c}{\Delta x}\right)}{\Delta x} = \frac{\Delta c}{\Delta t} \qquad D\frac{\partial^2 c}{\partial x^2} = \frac{\partial c}{\partial t}$$

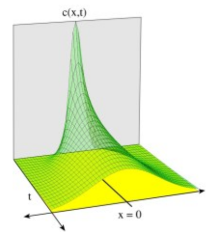
Lösungen:

- Für eindimensionale Diffusion:

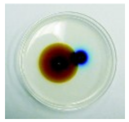
anim

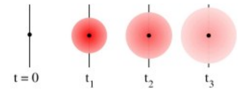
$$c(x) = \frac{c_0 \Delta x}{\sqrt{2\pi\sigma_x^2}} e^{-\frac{x^2}{2\sigma_x^2}}$$

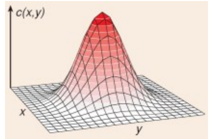
$$\sigma_x = \sqrt{2Dt}$$



- Für zweidimensionale Diffusion:

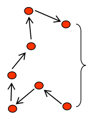






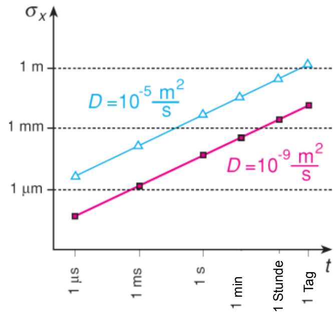
Siehe auch Praktikum!

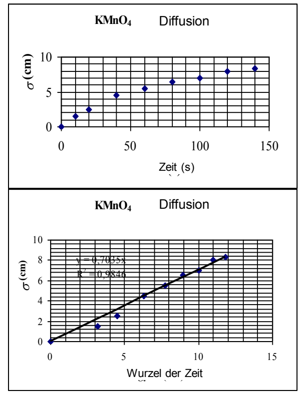
3. Diffusion als Random Walk



$\sigma = ?$

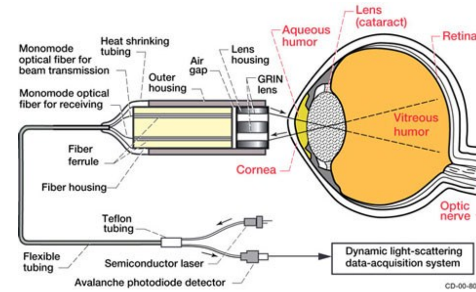
$\boxed{\sigma \approx \sqrt{2D \cdot t}}$





4. Anwendungen

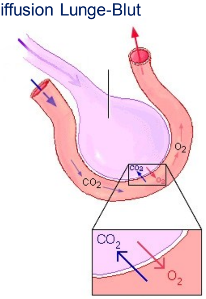
- Diffusion von Proteinaggregaten in der Linse ⇒ Größe der Aggregate

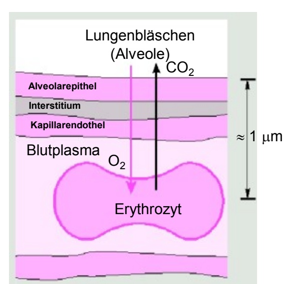


$$D = \frac{kT}{6\pi\eta r}$$

- Diffusion von Molekülen, Ionen in den Zahnschmelz

- O_2/CO_2-Diffusion Lunge-Blut

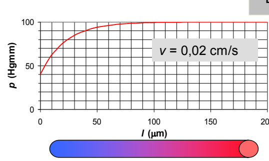




➢ 1. ficksches Gesetz:

Sauerstoffaufnahme

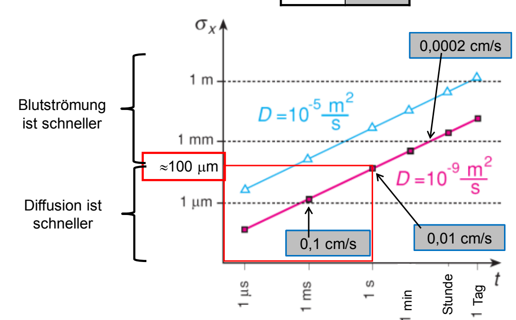
Excel



➢ Random Walk: 1 µm ⇒ 1 ms

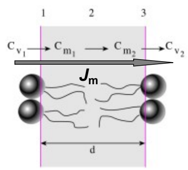
- Diffusion ↔ Blutströmung

Gefäß	Kapillaren
v (cm/s)	0,022



- Diffusion durch eine Membran (passiver Transport)

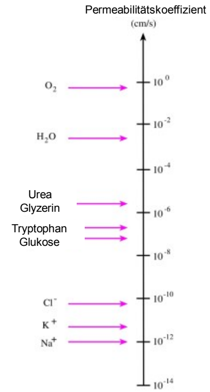
Für neutrale Teilchen:



$$J_\mathrm{m} = -D \cdot \frac{\Delta c}{\Delta x} = -p(c_{v2} - c_{v1})$$

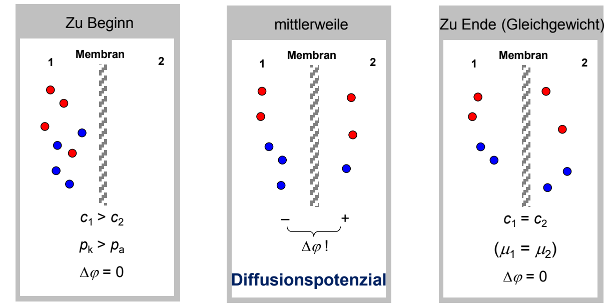
$$J_\mathrm{m} = -p(c_{v2} - c_{v1})$$

Permeabilitätskoeffizient (m/s)

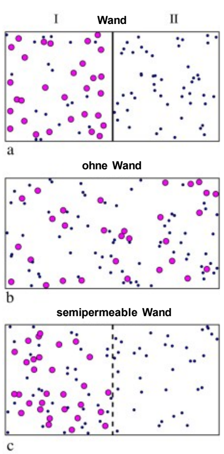


- Diffusion von Ionen durch eine Membran (ein Spezialfall)

einwertige Ionen: ● Kation (k) ● Anion (a) $p_k > p_a$



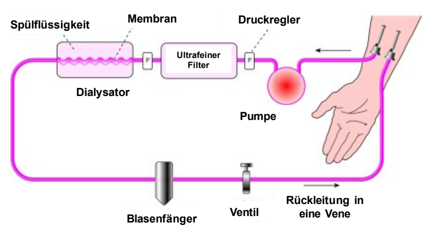
- Osmose



J. H. van't Hoff
1852-1911
Chemiker

Van't Hoff-Gesetz:

$$p_\mathrm{Osmose} = cRT$$



Biophysik für Mediziner: ■ III/2